shows the effect of light of a given intensity. It will be noticed that light makes the acted wire cuproid. But the action of mechanical vibration (see lower curve in same figure) makes the acted wire zincoid, and after several trials I found that a vibration with an amplitude of 3° produced a series of curves similar, but of opposite sign, to those produced by light. Thus mechanical vibration produced a molecular effect opposite to that of light.

I next allowed both the disturbing influences to act simultaneously on one of the wires, and the light action was then found to be exactly balanced by the action of mechanical vibration, an increase or diminution of either at once upsetting the balance.

The molecular effect of mechanical vibration thus appears, at least in the case of tin, to be opposite to that produced by light. This may be the case in general: the exception might be when one of the two stimuli is normal and the other sub-normal.

"On the Strain Theory of Photographic Action." By JAGADIS CHUNDER BOSE. Communicated by LORD RAYLEIGH, F.R.S.

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Our uncertainty with regard to the correct theory of photographic action is due to great experimental difficulties in studying the problem. As for instance:—

(1.) There is reason to believe that every substance is molecularly affected by radiation, but detection of change is rendered impossible by the imperfections of methods hitherto available, and also by the subsequent self-recovery of the substance in darkness. The effects can be detected in a few cases only when the changes produced happen to be visible, or become visible on development.

(2.) As regards direct chemical tests, if we take, for example, the case of AgCl, the quantity of radiation product is exceedingly small, and occurs in the presence of a very large amount of unchanged chloride. The isolation of the minute traces of changed product has baffled all effort. Again, there are produced various secondary reactions which complicate the phenomenon.

To arrive at a correct idea of the changes produced, it is necessary to measure the minute effects produced by radiation on the extremely thin layer—perhaps only a few molecules deep—of the sensitive substance. In order to ascertain this, it is desirable to begin with the study of some elementary substance in which its effects are attended with few secondary complications. And, lastly, it is necessary to have some means of studying all the stages of change in a continuous

manner, so that the important preliminary phase of "molecular negotiation" may not be missed. I have in my two previous papers shown how the above ideal requirements may be realised by taking advantage of the conductivity or electromotive variation methods.

These methods not only enable us to detect extremely minute molecular changes produced by radiation, but also to follow the changes moment after moment in a continuous manner.

I have described in the two previous papers the various molecular effects produced by light, electric radiation, and mechanical disturbance under different conditions. The consideration of these will give a clear insight into various obscure phenomena connected with photographic action, among which may be mentioned the following :—

1. Photo-chemical induction.
2. Relapse of invisible image.
3. Recurrent reversals.
4. The development of pressure marks.

1. "*Chemical*" *and* "*Physical*" *Theories of Photographic Action.*

It is an arbitrary distinction to call a phenomenon either physical or chemical when it happens to be on the common borderland. I have shown that when a substance is molecularly strained by light, its chemical activity is modified in consequence of the physical strain. The acted and the unacted portions will therefore be unequally attacked by a developer. In the case of a compound, the strain produced by light may cause a modification which renders it susceptible to decomposition by the action of a reducing agent. The observed evolution of chlorine when moist AgCl is exposed to the long-continued action of intense light is often adduced in support of the chemical nature of photographic action. This extreme case of dissociation cannot, however, be regarded as representative of the action of light in the formation of latent images. In ordinary photographic action we have merely the effect of a moderate stress producing the corresponding strain (with concomitant variation of chemical activity), and not the disruptive effect of a breaking stress.

With reference to photographic action, various facts are known which cannot be well explained from purely chemical considerations. In connection with this the following experiment of Professor Dewar is suggestive. It is found that at the low temperature of $-180°$ C., there is a cessation of all chemical action. Even such an extremely active substance as K does not show any action when immersed in liquid oxygen.* Now at these extremely low temperatures, where the action of such an active substance as K is suspended, an Eastman film was still found fairly sensitive to photographic influence.

* Dewar. Friday Evening Discourse at Royal Institution, June 26, 1891.

In the above case, it is difficult to see how light could have produced any chemical action in the relatively inactive silver salt. It is more likely that the effect produced was of the nature of some physical strain. That light does produce molecular strain even at such low temperatures —a strain which may remain latent—is shown from Professor Dewar's experiments on phosphorescence. Ammon. Pt. Cyanide cooled to $-180°$ C. in liquid air absorbs light, but emits feeble radiation. But as the temperature is raised the stored-up light is emitted with very great intensity.

I now proceed to consider the photographic interpretations of the various molecular response curves taken under the action of radiation, as detailed in my previous papers.

2. *Substances may be Sensitive and yet give no Photographic Image.*

The photographic effect on a sensitive plate is usually demonstrated by appropriate development, long after the exposure. The after-effect of light on the sensitive substance may be fugitive or persistent. There are numerous gradations of this persistency of after-effect.

In order that the effect of light may be "developed," it is therefore necessary that the portions corresponding to the image should not in the meantime have recovered from the strain due to radiation; for otherwise there would be nothing to distinguish the light-impressed portions from the other portions not affected by light.

Though almost all substances are molecularly affected by radiation, yet there is a great difference in the permanence of after-effects. The recovery, as has been mentioned before, is very quick in some cases, whereas in others it may be protracted.

It is obvious that any method which attempts to develop the after-effect a long time after the exposure will not be successful in cases where there is quick self-recovery. It will only be successful where the strain effect is more or less permanent.

It is thus seen that it is quite possible for a substance to be sensitive to radiation, and yet seem to show no effect capable of photographic development, owing to rapid self-recovery.

3. *Relapse of the Invisible Image.*

The above considerations afford a simple explanation of the very obscure phenomenon of the relapse of the invisible image. Recovery is merely a question of time. With certain substances it is immediate, with others it takes a little longer, as in a daguerreotype, where the latent image only disappears in the course of several hours. In ordinary photographic plates the recovery may not take place for several years. We have seen how the strain effect of electric radiation was transient in some cases, whereas it was persistent in others.

It is evident that in order to make the after-effect more or less permanent, and thus render it developable, self-recovery should be retarded. There are two ways in which the after-effect may be rendered comparatively permanent: (1) Even a highly elastic substance may be rendered more or less permanently distorted by straining it beyond the limit of elastic recovery; or (2) the presence of a retarding substance may prevent the self-recovery of the sensitive material. One of the chief functions of the so-called sensitisers may be to prevent self-recovery and make the after-effect permanent.

4. *Permanence of the Affect-effect by Overstrain.*

Thus in many cases where images cannot be obtained with ordinary exposure, they can be obtained with excessive strain caused by prolonged exposure. Thus Moser obtained an invisible image on a clean silver plate by exposing it to the sun for 2 hours or more. The invisible image was afterwards fixed by development with mercury vapour. A similar result was obtained with copper.

Major-General Waterhouse describes a very interesting series of investigations* in which by prolonging the exposure, printing-out impressions were obtained on silver. These could be developed not only by mercury or water vapour, but also by ferrous sulphate or pyrogallic developers. Images were also obtained on lead and gold.

All these results derive an additional interest from the fact that most of the phenomena that occur by the exposure of ordinary photographic plates containing haloid compounds of silver can also be observed upon a silver plate exposed to light. In my experiments on molecular effects produced by electric waves, I found *all* metals sensitive to electric radiation, owing to the extremely delicate nature of the conductivity method of detection. The molecular effects of visible radiation on various substances are also exhibited by the electromotive variation method. In the experiments of Waterhouse, a considerable number of metals were found to be sensitive to visible radiation, the effect being rendered more or less permanent by overstrain.

5. *Electromotive Variation Curve due to Light.*

I give below one out of several similar curves, showing the effect of continuous light on one of the two plates in a photo-electric cell of AgBr (see fig. 17). In this curve several distinct stages are noticeable.

(1.) A short latent period, where there is apparently little or no action or even a transitory negative action. The curve given had to be contracted to put in all the different phrases, and the peculiarities of the first part cannot be very well shown.

* Waterhouse, 'Roy. Soc. Proc.,' April, 1900.

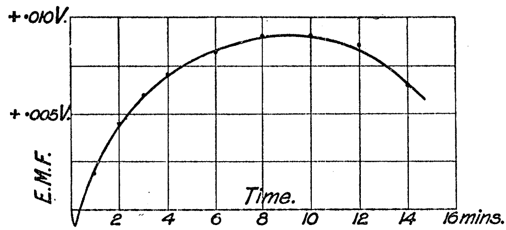

FIG. 17.—E.M. variation curve for AgBr cell, under the continued action of light. Note the preliminary negative twitch.

I have previously remarked that the molecular strain curve in general is in the first part slightly convex, then straight, and in the last part concave; this is true not only when the strain is produced by light, but also by mechanical vibration.

(2.) After this stage, the curve of response rises almost in a straight line. This is the stage of increasing action.

(3.) The curve then reaches the maximum and becomes horizontal; after which it begins to fall, till it reaches the original neutral line.

(4.) After very prolonged exposure I have sometimes found the curve proceeding in the *negative* direction, thus exhibiting molecular reversal.

I have before explained the similarities of the molecular strains produced by light and mechanical vibration. The recurrent reversals are also sometimes obtained with mechanical vibration, as in the following electromotive variation curve for nickel (see fig. 18), which was kept for a long time under constant mechanical vibration.

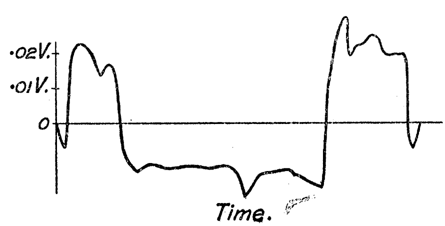

FIG. 18.—Recurrent reversals obtained with a Ni cell under continued vibration.

6. *Photo-chemical Induction.*

The first part of the curve, or the latent period, is very suggestive as regards the obscure phenomenon of photo-electric induction. Thus "Quantitative measurements have shown that the action of light is not instantaneous. On the contrary, it gradually develops, and requires a considerable time before it attains its full strength. When a mixture of chlorine and hydrogen, which have been kept in the dark, is exposed

to the light, there is either no hydrochloric acid or only a very small quantity formed in the first moment; but the rate of formation increases so that the quantity formed in a given time, *e.g.*, a minute, continues to increase until it attains a maximum value. Bunsen terms the gradual increase in the action *induction.* If the gaseous mixture has been once exposed to the light, it will retain in the dark, for about half an hour, its capacity for forming HCl in the light. If the gas has remained in the dark for a short period and is again brought into the light, it requires a very short period of induction; but the period of induction will be lengthened by keeping the mixture in the dark for a long time. [This is evidently due to self-recovery.—J. C. B.] Exposure to the light renders the gaseous mixture capable of entering into combination, but it does not bring about combination itself."*

The latent period of the curve, due to molecular inertia, would thus appear to offer an explanation of induction. In connection with this it is interesting to note the well-known fact that a very slight preliminary exposure of the photographic plates considerably enhances their sensitiveness.

It would also appear from the inspection of the curve, that the general law of photo-chemical action, which regards the total action as proportional to the product of the light intensity multiplied by the time of exposure, is subject to several modifying conditions. During the latent period, this cannot hold good in the first part, nor can it be true after the maximum is reached. It can hold good only in the second stage when the action proceeds uniformly.

7. *The Effect of Intermittence in Modifying the Law of Photo-chemical Action.*

But even after the substance has arrived at the second stage of uniform action, there may still be deviation from the above law. If in one case light be intermittent, and in the other continuous, the effects may be quite different, though the total durations be equal. For in the former case, during the continuation of light we may have distortion or molecular swing proceeding in a given direction, but on the stoppage of light, the swing stops too, sooner or later (sooner if the distortion has been considerable, when the force of restitution becomes great), and owing to self-recovery may even become reversed. After an interval, when the light is again allowed to act, it has not only to overcome the molecular inertia, but may have in certain cases to reverse the negative swing. In the case of continuous radiation, on the other hand, the molecular action proceeds without hindrance.

This is very well seen in the curve given below, which shows the difference in the extent of molecular effects produced in an AgBr

* Meyer, 'Modern Theories of Chemistry,' p. 507.

cell by interrupted and continuous illuminations of the same total duration. (See fig. 19.) Though light acted for the same length of time in both cases, yet in that of interrupted illumination the molecular effect as measured by the galvanometer deflection was only seven divisions, whereas with continuous illumination the deflection was 11·5, or one and a-half times as great.

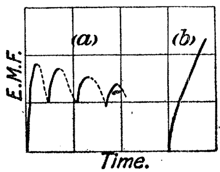

Fig. 19.—Effect of (*a*) intermittent and (*b*) continuous illumination. In (*a*) there are four interrupted illuminations of 15″ each, the total duration being 1′. In (*b*) there was continuous illumination for 1′.

It is thus seen that owing to self-recovery, the effect of light with intermittent illumination is less. It is also evident that the greater the period allowed for self-recovery (during the interval of darkness) the less will be the resultant effect. In connection with this, the experiments of Abney are very interesting. In experimenting on the difference between the effects on photographic emulsion of a continuous exposure and a series of intermittent illuminations, he finds that in the latter case the effect produced was always less, and that the longer the interval between the exposures, the smaller was the effect.

8. *Photographic Effect Modified by Time-rate.*

It will thus be seen that the photographic effect is not solely governed by the total amount of radiation, but by the time-rate also. The influence of this factor appears to be exhibited in the three following cases. Cases (2) and (3) derive an additional interest from the fact that the effects are probably due not to absorption of radiation, as is usually the case in photography, but to the emission of radiation.

(1.) In photographs of lightning, the line of discharge often comes out dark (the so-called dark lightning). It has been shown that reversals are produced by intense radiation; we may thus have reversals of the first, second, and succeeding higher orders. Now it is possible that the reversal, or the dark-lightning effect, may be obtained, not only by a subsequent diffuse illumination (Clayden effect), but also by the action of lightning itself, provided that the intensity of illumination is sufficiently great and sudden to produce the reversal. The luminous intensity of lightning discharge is incom-

parably higher than any that can be produced by a spark from an electric machine. Mr. R. W. Wood* obtained reversal with a single spark, when the photographic lens was wide open, but there was no reversal with four sparks, the lens aperture being reduced to one-fourth. The quantity of light was the same in the two cases, but the time-rate of illumination was different. This curious result would no longer appear anomalous, if we bear in mind the experiment in which the influence of time-rate was shown.

(2.) In trying to obtain photographs by heat radiation on sensitised papers coated with a mixture of silver and mercury iodides, the following curious effect was observed. The sensitised paper was exposed to heat radiation and became uniformly reddish in colour. A mask with cut-out letters was now put on it, and the sensitised paper was allowed to cool. The rate of cooling was very rapid at the places exposed by the cut-out letters, whereas at the covered portions the rate of cooling was very much less. After a long time when the sensitive paper had cooled down to a uniform temperature, prints were still visible, the effect being evidently due to the different rates of emission in the screened and unscreened parts.

(3.) Major-General Waterhouse in his paper† mentions an anomalous case which seems to be explicable from considerations given above. He took a polished silvered glass plate, and put it into a printing frame with a cut-out paper mask and mica screen in which were cut-out initials, just as if it were going to be exposed to the sun; but instead of exposure to light the plate was gently warmed for about 5 minutes over a spirit lamp, and then developed with mercury. The cut-out initials came out distinctly in dark lines. It seems to me that in this experiment, as the plate was uniformly warmed, the difference between the screened and unscreened portions could only be in the different rates of emission.

9. *Phenomenon of Recurrent Reversals.*

The fourth stage in the curve for the action of light (see fig. 16) will be found specially interesting with reference to photographic reversals. These reversals are found to be recurrent. Thus, starting with a neutral condition, we obtain the first negative with a moderate exposure; longer exposure will tend to reduce the intensity of the negative and give rise to a neutral condition. Further exposure gives rise to a *positive*, then a second neutral, and again a succeeding negative stage, and this often goes on in recurrent series.

Such recurrent reversals are also exhibited (see fig. 18) by a substance under continuous mechanical vibration. In my paper on "Elec-

* 'Nature,' November 30, 1899.

† *Loc. cit.*

tric Touch"* I have given similar instances of reversals produced by the action of long-continued electric radiation.

10. *Other Methods of obtaining Latent Image.*

If molecular strain be the basis of all photographic phenomena, then it ought to be possible to obtain latent images by other methods of producing molecular strain.

An instance of this is seen in the development of mechanical pressure marks. Images produced by electric strain are seen in the "inductoscripts."

11. *Conclusion.*

It is thus seen—

(1.) That molecular strain is produced by the action of light.

(2.) That as the physico-chemical properties of a substance are changed by strain, it is possible to develop the latent image through the difference in the following properties between the exposed and unexposed portions produced by light—

(*a.*) Difference in adhesive power, *e.g.*, development of daguerreotype by mercury vapour, development by water vapour.

(*b.*) Difference in chemical stability, *e.g.*, development by reducing agents.

(3.) That molecular strain may not only be produced by visible or invisible radiation, but also by (*a*) electric induction, (*b*) mechanical distortion. Latent images produced by such means may be developed, *e.g.*, inductoscripts, development of pressure marks.

(4.) That nearly all substances are sensitive to radiation, but the effect cannot in all cases be rendered visible, (*a*) owing to want of suitable chemical developers, (*b*) owing to quick self-recovery. The molecular effect due to radiation can, however, be demonstrated by the conductivity or electromotive variation methods.

(5.) That the latent period of overcoming inertia corresponds to the photographic induction period.

(6.) That the relapse of image is due to self-recovery.

(7.) That owing to the tendency towards self-recovery the radiation effect does not solely depend on the total quantity of light, but depends also on the time-rate of illumination. Hence the photographic effects of intermittent and continuous illuminations are not the same.

(8.) That the continuous action of radiation produces recurrent reversals.

(9.) That the molecular effects produced by light and electric radiation are similar.

* 'Roy. Soc. Proc.,' vol. 66.